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A New Passive-Active Method of Protection from Dynamic Vortex Atmospheric Structures: Physical Foundations, Technical and Economic Advantages

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Abstract

The present paper relates to the new method and system for protecting areas or regions from destructive dynamic vortex atmospheric structures such as tornadoes, cyclones, and the like. The proposed method is based on creating and positioning one or more vertical mesh structures between the approaching non-stationary atmospheric vortex and the object to be protected. The paper describes the key ideas, on which the developed method for protection of local areas against dynamic vortex structures is based.

Keywords: Tornado Protection, Vortex Atmospheric Structure (VAS), Passive-Active Method, Mesh Structures, Physical Principles

I. INTRODUCTION

Vortex motion is a very widespread form or air motion. There exist many kinds of vortex motion of the atmospheric air, differing in sizes, characteristic velocities, and lifetimes. We will mention only those vortex motions that have catastrophic effects, such as whirlwinds (tornadoes), vortex storms and hurricanes [1-10].

Every year, atmospheric vortices of different scales (hurricanes and tornados) cause human casualties and huge financial damage. Today, no efficient methods for controlling natural phenomena exist; therefore, the issues of generation and development of atmospheric vortex formations are very important.

The main tasks in investigating atmospheric vortex formations are as follows [11]:
1) the weather forecasting and evaluation of the probability of natural calamity development in a specific place at a given time, as well as prediction of the direction of movement of the currently developing natural phenomenon;
2) the studying the opportunities for weakening and dissipating a vortex structure and for changing its path.

All of the proposed and developed methods of impact on atmospheric vortices can be divided into two classes: passive and active. Passive methods include: constructing stable low buildings, enhancing dams, etc. Active methods can be subdivided into two groups: preventive methods used to prevent natural calamities, and direct methods used to eliminate (weaken) the developing natural phenomena.
A several words should be said about preventive methods. Great efforts have been applied to develop methods for decreasing the air instability resultant in atmospheric vortex formation. These methods include “warming-up” of the upper part of the hurricane (tornado) and “cooling-down” of the vortex structure basis.

For instance, for “warming-up” the clouds, the staff of the Massachusetts Technological Institute proposed spraying carbon particles, such as soot and motor tire waste from the cars. Dark particles are heated intensively by the solar radiation, thereby, increasing the temperature of the cloud. Besides, it is also proposed to heat the cloud over the center of the hurricane using microwaves from satellites.

For “cooling-down” the air near the hurricane basis, for example, the specialists of the Hebrew University of Jerusalem proposed to introduce small-sized dust particles into cumulonimbus clouds. It is assumed that fine particles will rapidly absorb water, but the generated drops will be too small to fall to the ground, but rather will be lifted and evaporate. The evaporation process will lead to cooling the air near the atmospheric vortex basis. The use of other reagents (for example, solid carbonic acid and silver iodide), accelerating the condensation process, will also decrease the probability of spontaneous condensation and, hence, the probability of generation of a tropical cyclone. Also, it is proposed to reduce the evaporation intensity in order to exclude generation of a heated air layer near the water surface by depositing special films on the surface. Of course, environmental requirements demand complete disintegration of the films after some time.

Nevertheless, all of the above methods for prevention of natural calamities, which are extremely expensive, turned out to be inefficient.

The direct methods are more efficient and effective. One of the efficient and, at the same time, specific methods of destroying tornados, is the explosive method. It is well known that several centuries ago sailors tried to destroy water tornadoes by means of onboard guns. N. Tesla proposed the method for destruction of tornadoes by arranging a local explosion (inside the funnel or very close to the funnel), delivering the explosives by means of remote-controlled unmanned aerial vehicles. Similar proposals are made today,

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too. It is evidently, that the main problem of using any active means for tornado control (for example, a nuclear charge) is that this charge can be much more lethal and damaging than the tornado itself. The less efficient means (such as huge heaps of dry ice or conventional arms) are very difficult to be deployed rather rapidly in the right place; moreover that in any case they will not have sufficient shock force to affect the tornado.

The above suggests the conclusion that no efficient and economically sound methods for controlling natural calamities exist today. Therefore, laboratory investigations of the issues of generation, stability, and control of behavior of non-stationary wall-free air vortices, close by their structure to atmospheric vortex structures, represent a very urgent problem.

II. PREVIOUS EXPERIMENTAL RESULTS AND BASIC IDEAS OF THE METHOD

Simulating dust devils and tornadoes in laboratory conditions is not a new concept. Steady-state vortex flows bounded by walls are generated by means of fans, mechanical swirling devices (guiding swirling blades, screws, augers, inner spiral ribs, etc.), as well as by a tangential nozzle supply of the medium and intense rotation of the channel body elements (rotating tubes). The major of these experiments were collected in review paper [12].

Stationary and quasi-stationary vortex flows are very convenient for detailed experimental description. However, their characteristics and, especially, behavior and interaction with different structures may significantly differ from the parameters of real unsteady vortex structures observed in Earth atmosphere. Perhaps, the study of wall-free non-stationary concentrated (the vorticity is localized in space) vortices is complicated by a number of reasons such as spontaneity of generation, space-time instability, practical impossibility of controlling the characteristics, and so on. The difficulties mentioned above account for the apparent absence of experimental studies producing results in generation, stability and dynamics of wall-free non-stationary concentrated vortices.

In [13] the authors demonstrate the fundamental possibility of studying the questions of generation and stability of wall-free non-stationary concentrated air vortices under laboratory conditions without using of mechanical swirling devices. These vortices were produced over underlying surface of aluminum sheet due to its controlled heating from below as a result of unstable stratification of air.

An effect of different mesh structures on the wall-free non-stationary air vortices has been experimentally studied by authors in [14]. The experiments revealed six basic patterns of behavior of vortices, namely,

(i) the vortex breakdown in the vicinity of the mesh structure without crossing the latter;

(ii) the deceleration of vortex near the mesh (down to complete stop) and subsequent breakdown;

(iii) the vortex motion along the mesh (without crossing the mesh), and breakdown;

(iv) the vortex breakdown during crossing the mesh;

(v) the vortex breakdown on the mesh with re-generation of the vortex after the mesh; and

(vi) the vortex crossing of the mesh, accompanied with the change of direction and characteristics (attenuation of vortex).

The several fundamental mechanisms of how mesh structures affect a non-stationary vortex have been distinguished. Among these mechanisms is the action of small-scale turbulence generated behind the mesh with large-scale turbulence of the model vortex, leading to violation of its symmetry. The generalization has been made of the data obtained concerning the influence of net structures of various geometries on the laboratory-simulated vortices of different intensities.

III. BASIC IDEAS OF THE METHOD

As a rule, non-stationary vortex atmospheric structures (called here as VAS) are formed and stabilized under isotropic conditions near the Earth surface along a smooth plane. For all VAS that exist for a significant length of time, the two previously mentioned conditions (isotropic conditions and smooth plane) are the factors necessary for their occurrence and subsequent continuation. It is well known that all VAS continuously change their parameters in the course of their existence and constantly preserve their vortex structure. Despite various theories and hypotheses, the nature of the physical model and the basis of the VAS and its stability do not have adequate scientific explanations as yet. However, from numerous physical observations and modeling experiments, several factors have been identified as being associated with the destabilization and destruction of VAS. These factors include friction of air near the ground plane, VAS encountering ground heterogeneity (constructions, woods, etc.) and interaction with other atmospheric flows and pressure differences. A primary factor, and one which is most apparent, which promotes a typical natural destruction of a VAS, is the disruption of physical conditions necessary for stabilization of the vortex structure occurring as a result of interaction with external factors.

The proposed method is based on creating and positioning one or more vertical mesh structures between the approaching non-stationary vortex and the object to be protected. Due to the interaction between the mesh structures and the non-stationary vortex, a non-stationary gasdynamic turbulent field is created with significant anisotropy of physical parameters, such as density, pressure, velocities of secondary flows, and parameters of turbulence.

Fig. 1 is a schematic illustration of a non-stationary VAS, depicting mean velocity vectors (U_z, U_r, and U_φ) and their respective directions (vertical z, radial r, and tangential φ). Fig. 1 also illustrates the area of the mesh structure. Extending around the periphery of the VAS are radically directed air flows generated by a radial pressure gradient. It can be seen that the simple mesh structure consists of a combination of vertically and horizontally oriented elements. The power of the secondary turbulent field created by the mesh structure is transferred from the power of the VAS, increasing nonlinearly with the spatial position of the mesh structure relative to the VAS. The effective power of the secondary field generated by the mesh structure also increases nonlinearly.

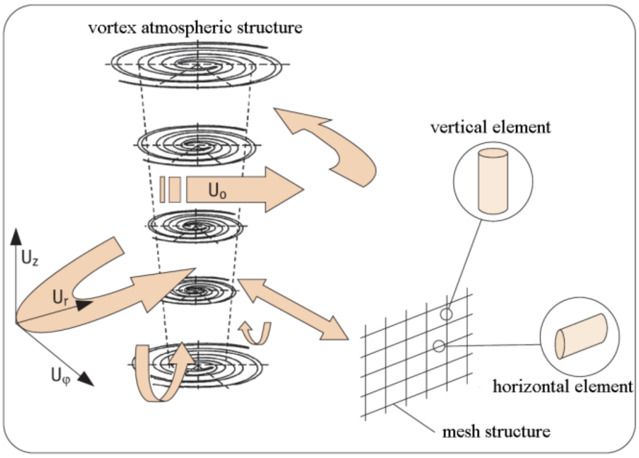

Fig. 1. Scheme of the non-stationary vortex atmospheric structure and mesh structure

The formation of a secondary field of turbulence and interaction of physically interrelated fields, for example, interaction between the turbulent field of the VAS and the non-stationary secondary field of turbulence generated by the mesh structure, is the primary factor contributing to local disturbance of symmetry and isotropy of the surrounding space around the VAS. Nonlinearly increasing asymmetric influence of a secondary field on the vortex structure of the VAS leads to local violation of the law of conservation of mass and violation of the law of zero-sum conservation of moments of the external forces of the VAS. This, in turn, leads to subsequent destabilization and, ideally, to the ultimate destruction of the non-stationary VAS. It is strictly emphasized that the power required for the destabilization and destruction of the vortex structure is taken from the power of the vortex structure itself. The proposed method does not require external power sources for an influence on the atmospheric vortices such as tornadoes.

The present method provides means for local protection of regions having structures, such as buildings from destructive non-stationary VAS. These methods involve disrupting or destabilizing a non-stationary vortex by means of turbulent fields generated by the secondary flows, created by the interaction of the atmospheric vortex with the vertical meshes. The mesh should be, preferably, located between the non-stationary VAS and the object or the region to be protected. This mesh structure should be in the form of a cluster of spatially oriented discrete mechanical elements, which transform the power of the local turbulent flow of the non-stationary VAS to the power of small-scale turbulent fluctuations (a secondary turbulent flow). The secondary turbulent flows exhibit a greater degree of turbulence than the local turbulent flows from the VAS.

In the power-consuming process of formation of secondary turbulent flows, every individual element should play the role of the aerodynamic “converter” of power and the generator of local high-pressure areas. The interaction between an individual element and an air flow associated with the VAS is defined by the geometry of the individual element only and its orientation relative to the velocity of the flow (see Fig. 1). For example, the vertical element interacts with the radial (U_r) and tangential (U_φ) components of the local (near vertical element) velocity vector of VAS and, therefore, generates the secondary turbulent flow in the radial and tangential directions, respectively. Meanwhile, the horizontal element interacts with the vertical (U_z) and radial (U_r) components of the local velocity vector of VAS and, therefore, produces the secondary turbulent flow in the vertical and radial directions, respectively.

IV. ADVANTAGES OF THE METHOD

The new results of previous investigations [13, 14] allowed us to propose a method for their control. This method represents the placement of mesh-type barriers of certain geometry along the path of vortex atmospheric structures. Below, we enumerate briefly the basic physical mechanisms (principles) of the influence of the proposed method on tornadoes, which predefine its advantages.

IV.I Non-use of a solid barrier

Solid barriers (such as a solid fencing) are passive methods for protection against tornadoes. Due to the solid structure, the total force of tornado impact on such barriers is maximal. For instance, the average tornado, F5 by the Fujita scale, with the maximum speed 130 m/s, exerts effort on the solid barrier equal to about 10,000 N/m^2. Therefore, it should be rated for such impact. This makes solid structures very expensive. Taking into account the tornado “jumping” effect, such barriers do not provide 100% protection against tornado, despite their big height. The proposed mesh structures have aerodynamic resistance that is ten, sometimes dozens, times smaller. Analysis of multiple destructions caused by tornado testifies to high resistance of mesh structures compared to solid barriers. This circumstance makes such structures much more cheaper compared to solid barriers.

IV.II Small-scale turbulence generation

The proposed vertical mesh structures, under specific conditions [14] will generate secondary flows. In a general case, the flow is non-stationary, non-homogeneous, and three-dimensional and, which is very important, has the velocity component directed toward the tornado funnel. Thus, the proposed method of protection is passive and active at the same time. It is passive, because the system is in the condition of waiting of the coming vortex structure. It is active, because it assumes aerodynamic interaction of the mesh barrier with the oncoming vortex flow, resulting in destabilization and/or destruction of the VAS. It should be noted that, unlike all active methods of protection, the proposed method does not require external power sources. The power needed for exerting impact on the VAS is taken from the vortex itself.

IV.III Aerodynamic increase of the working surface

Elements of the mesh barrier generate, in specific modes, turbulent traces the size of which always exceeds their characteristic dimension (for instance, the wire or rope diameter used in the mesh structure). At some distance from the mesh obstacle plane, the turbulent traces begin interfering with each other, resulting in the effect of aerodynamic increase of the originally small "working" surface, making it close to the maximum value typical of the solid barrier.

IV.IV Vortex-mesh long-distance interaction

By use of condition of small-scale secondary turbulent flow generation toward the oncoming vortex due to vortex-mesh interaction and assuming the Rankine vortex distribution of velocity, it is easily to estimate the distance at which the "work" of the protective mesh structure begins [14].

The received results indicate that even the weakest tornados begin to interact with mesh structures at distances of hundreds of meters. Thus, the disruption of atmospheric vortices using the mesh structures begins at significant distances from objects to be protected.

IV.V Increasing impact with decreasing distance

With decreasing distances between tornadoes and the protective mesh structure, the velocity of air suction through the structure increases, which definitely increases the power of the small-scale turbulent flow generated by the mesh barrier. This enhances the impact of the mesh barrier on the oncoming tornado.

IV.VI Small height of the protective mesh structure

A vertical mesh barrier arranged along the tornado path affects the swirling flow, developing near the ground and generating the atmospheric vortex. As clearly demonstrated by the experiments made by the authors [14], mesh structures with the height ten-fifty times below the visible height of the modeled laboratory vortex were very efficient. This allowed us to make a conclusion that the height of the ground layer where the ascending twisted flow exists is also dozen times smaller than the full tornado height. Given the typical height of real tornados, the height of mesh protective structures should be relatively small (for instance, 5–8 m) and comparable to the height of the protected dwelling structures.

IV.VII Increasing of relative size of mesh protective structure with decreasing distance

With decreasing distance between the tornado and the mesh structure, the curvature of the streamlines of air flowing through the barrier decreases. This results in the increasing length of the mesh barrier and higher non-homogeneity of the generated secondary flow, destabilizing the VAS.

IV.VIII Rapid and seasonal installation

Due to their simplicity, mesh protective structures can be installed within a brief time, for instance, in a few minutes. This is an obvious advantage of mesh structures over any passive method of protection against tornados. Mesh structures can be installed for some seasons, for instance, only for the peak season of tornadoes, for one or two months. Moreover, mesh protective structures can be designed as seasonal superstructures (1–3 m high) of the available stationary protective structures. For better efficiency, such protective structures (1–3 m high) should also meet the requirements to mesh protective structures (non-solid, etc.).

IV.IX Protection against debris

In addition to efficient impact on the underlying surface hydrodynamic structure, mesh protective structures ensure excellent protection against debris of various sizes and origins.

V. CONCLUSIONS

The mesh barriers (obstacles) whose efficiency was explicitly demonstrated by the author`s experiments may be the most cost-effective among all methods proposed for today for controlling air tornadoes, due to simple fabrication and low costs.

It is possible to make a conclusion that people are completely helpless in combating natural calamities; the examples are numerous, and they are all too well known.

Perhaps, it may be stated that the existence of whirlwinds, characterized by relatively small space and time scales and low energy, gives the mankind the possibility to begin from small things – to develop means of protection against such whirlwinds.

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